# MARKETS FOR CHEMICALS FROM A

# PYROLYSIS OIL

# BIO-REFINERY IN NEW HAMPSHIRE

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## EXECUTIVE SUMMARY

This report has been prepared to assess the market for chemical products derived from a wood-based pyrolysis oil facility in New Hampshire. It builds upon the results of a study titled "New Hampshire Bio-oil Opportunity Analysis" prepared for the New Hampshire Governor's Office of Energy and Community Services (now the NH Office of Energy and Planning) by Innovative Natural Resource Solutions LLC, dated September 2004. In addition, this report updates the price analysis of wood used as a raw material for a bio-refinery. The project is intended to support the economic evaluation of site- specific opportunities for a wood- based pyrolysis oil bio-refinery in New Hampshire that is being carried out by Gerald Stewart of Cole Hill Associates. The focus of both of these studies is on the feasibility of establishing a commercial-scale facility in New Hampshire that would utilize the abundant low-grade wood available in New Hampshire's forests and support economic development in the state.

### MAJOR FINDINGS OF THE STUDY

1) There is a large number of products from a pyrolysis oil based bio-refinery that have been produced in experimental reactors or demonstration plants. Most of these products are similar to, or are substitutes for, products of petroleum or natural gas, which makes them attractive as part of a biomass-based production system that reduces dependence on petroleum, reduces greenhouse gas emissions, and supports domestic rural economies. In addition, there are some products such as certain food additives, fragrances, and possibly pharmaceuticals that can only be produced from biological materials.

2) The major commercial products of existing pyrolysis oil bio-refining facilities are pyrolysis oil, gas, and char that can be used as fuels. Char can also be used to produce refined charcoal for a variety of purposes. The other major products that have been produced on a commercial scale and marketed are food flavorings, food additives, and natural phenolic resins. Natural phenolic resins can be used as a partial substitute for petroleum-based phenolic resins in Phenol Formaldehyde (PF) resins. PF resins are used in the manufacture of oriented strand board (OSB), plywood, and other engineered wood products. As the objective of the study was commercial production in New Hampshire, these existing commercial products are the focus of the report.

3) There is only one company in North America, Ensyn Corp. based in Ontario, Canada, with the demonstrated capability to build and operate a commercial bio-refinery based on pyrolysis oil from wood. However, for the production of food flavorings, additives and related products this capability is dependent on proprietary technology belonging to Red Arrow Products Company of Manitowoc, Wisconsin.

4) There are several potential models for a bio-refinery, but there are only two models for a bio-refinery based on wood pyrolysis oil that are currently commercial or near commercial. These are the Food Additives Model and the OSB Model.

*The Food Additives Model*

In this model a pyrolysis bio-refinery is optimized to produce carbon-based liquids that have specific flavors, aromas, color, or cooking properties. These are very high value products by weight compared to pyrolysis oil. The technology is driven by the specific requirements of the additive manufacturer and the market. The co-products of the process are pyrolysis oil and char which are used as a fuel for the operation of the food additive manufacturing plant. Wood characteristics and species are important; that is, certain species yield higher quantities of desired products. The pyrolysis facilities do not need to be very large to achieve economies of scale. This model is exemplified by the two Red Arrow plants at Rhinelander, Wisconsin where the company's liquid smoke product is made. The key factor in economic feasibility is the manufacturing company's technology and marketing capability. At present, Red Arrow combined with Ensyn are the only companies in North America with the technology to produce these types of food additives in a commercial, integrated bio-refinery. Additional facilities using this model are dependent on licensing agreements with Red Arrow. At present, it seems highly unlikely that Red Arrow would choose to expand its operations to New Hampshire.

*The OSB Model*

In this model, a pyrolysis oil bio-refinery is used to produce a phenolic resin raw material used in the Phenol Formaldehyde (PF) resin for manufacturing OSB. At present the phenolic resin used in PF resin that meets the APA product performance standards for OSB contains no more than 40% resin made from pyrolysis oil. The bio-refinery at an OSB plant can also provide pyrolysis oil and char as fuel for the OSB plant. Waste material, including bark, from OSB manufacturing can be used as feedstock for the bio-refinery. OSB made in part from biological resins could command a "green" premium price. This model has yet to be implemented on a commercial scale. However, it appears to be an attractive model and we believe this option is being actively pursued by at least one partnership. There are no OSB plants in New Hampshire and other OSB plants are distant. The most attractive locations for new or expanded OSB production are in the US South or parts of Canada. It is therefore very unlikely that this model could be developed in New Hampshire.

5) Although the principal focus of this study is the market for non-fuel products, a preliminary review of the possible markets for pyrolysis oil alone was undertaken. This model considers the market prospects for pyrolysis oil sales to an existing or new commercial or industrial user of #6 fuel oil, or distillate fuel oil, who has no business partnership with the pyrolysis oil producer. The most likely customer would be a government agency or institutional user, such as a college or university, for whom the environmental benefits would be a factor in the decision. The conclusion of the review was that it is highly unlikely that any such customer would elect to use pyrolysis oil. This conclusion is based on the additional fuel handling and boiler modification costs, regulatory uncertainty, and product availability and price risks. This conclusion applies even if the fuel were provided at a lower cost per Btu than conventional fuel. The disadvantage that pyrolysis oil has, when compared to conventional fuels or biodiesel, could only be overcome by the producer or the public sector carrying the additional cost.

6) The review of the prices for wood that may be used in a bio-refinery shows that wood prices have increased in New Hampshire to the high $20s per ton range from around $18 per ton through most of the 1990s. Wood prices tend to increase with increasing oil prices and are subject to other uncertainties in the future. The conclusions of the wood prices study do not fundamentally change any of the other conclusions of this report. However, the current price of wood makes New Hampshire and New England generally less attractive as a location for wood-to-energy projects than Canada and some other parts of the United States. This tends to reinforce the conclusions that follow.

## CONCLUSIONS

1) The primary overall conclusion of the study is that the prospects are poor for developing a commercial bio-refinery based on pyrolysis oil from wood in New Hampshire. Only Ensyn has the demonstrated capability to make products other than oil, gas and char and Red Arrow owns the technology to produce food additives by this process. Food additive manufacturing by Red Arrow is clearly economically feasible but the cost and pricing structures are proprietary. However, it is unlikely that Red Arrow would expand operations in New Hampshire. Even if a Red Arrow plant were built, the typical wood consumption levels of about 100 tons per day are not the basis for a significant economic development on its own. Natural resins to make PF resins for OSB have been produced in commercial quantities by Ensyn for demonstration purposes but full-scale commercial application would require a partnership with an OSB manufacturer. This would most likely occur in the Southern US or in Canada.

2) A secondary conclusion is that open market sales of pyrolysis oil are not practical at the present time in New Hampshire, even if the price on a heat content basis were at or below conventional oil. This is because of the additional costs and risks associated. At present pyrolysis oil is not a proven commercial fuel. It could be used in a pilot or demonstration facility by a steam or steam-electric generator in partnership with one of the three pyrolysis oil manufacturers. Based on the experience with several plants in Canada and one under development in Massachusetts, this would require a subsidy of between 50% and 80% of the capital cost, assuming that the wood supply is relatively low-cost waste. If the wood were to be harvested at current market prices, then other subsidies would probably be needed. If electric power were generated and sold into the Massachusetts or Connecticut Renewable Portfolio Standards (RPS) markets, then the level of subsidy might be reduced. However, there are unresolved inter-state policy implications in how a subsidized electric generator in one state might be treated by another.

3) The conclusions of this study apply only to pyrolysis oil based bio-refining in New Hampshire. Other wood based technologies such as gasification, enzymatic conversion to ethanol and direct industrial-scale combustion have different attributes, production economics and markets.

## INTRODUCTION AND PURPOSE

This report has been prepared to assess the market for chemical products derived from a wood-based pyrolysis oil facility in New Hampshire. It builds upon the results of a study titled "New Hampshire Bio-oil Opportunity Analysis" prepared for the New Hampshire Office of Energy and Planning by Innovative Natural Resource Solutions LLC dated September 2004[1](Bio-oil Opportunity Analysis). In addition, this report updates the price analysis of wood used as raw material for a bio-refinery. This study is intended to support the economic evaluation of site-specific opportunities for a bio-refinery in New Hampshire based on wood pyrolysis oil that is being carried out by Gerald Stewart of Cole Hill Associates.

## BACKGROUND

The economic conditions in which to evaluate the bio-refinery concept are fundamentally unchanged since the completion of the New Hampshire Bio-Oil Opportunity Analysis in 2004. There has been a marked increase in the cost of oil and natural gas during 2005 associated with worldwide supply shortages. These historic high oil prices may bring about some re-evaluation of the markets for alternative energy sources, however this study is based on information gathered before the full magnitude of the these increases was known. It remains to be seen whether oil prices will remain high for an extended period and what will be the consequences.

## METHODOLOGY

This is principally a market evaluation study, the usual methodology for which is to collect and analyze information on the size and location of the market for specific products and their prices. Initially we assumed that this could be pursued by traditional market research methods using surrogate products for pricing products not yet fully commercial. During our review of the products that could be made in a bio-refinery it became apparent that there were very few products, other than pyrolysis oil, that had been made on a commercial or near-commercial scale and that these were typically part of a larger, integrated operation in which it was very difficult to determine the economics of production of individual components. Most of the financial and technological information in this field is proprietary.

In reviewing what had been accomplished in North America, it became apparent that there was only a small number of models for wood-based bio-refineries which were commercial or near-commercial. Therefore these models were evaluated to see if they could be applied or adapted to the New Hampshire situation. The parameters for this study are that we only considered bio-refinery models that were commercial or near commercial, which implied that there had to be at least one company with the demonstrated capability of building and operating a bio-refinery. The focus is on bio-

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[1] "New Hampshire Bio-oil Opportunity Analysis" prepared for the New Hampshire Office of Energy and Planning by Innovative Natural Resource Solutions LLC, September 2004

refinery products in addition to oil, gas, and char as fuels. However, in the process the capability and the market for stand-alone pyrolysis oil production were also reviewed. This study does not evaluate products that are only at the research and development or pilot plant stage unless there is a clear route to commercial production.

The process for gathering information relied upon a review of publicly available information, interviews with experts in research organizations, industry, and government. Some information was obtained under a confidentiality agreement, which prevents disclosure. In other cases experts were willing to provide information for the report but did not want to be quoted directly or cited. In view of the proprietary nature of much of the information and the competition that exists for the small amounts of government support, this is understandable. However, information that is central to our major findings and conclusions has been in most cases documented or corroborated by two or more independent sources.

## REVIEW OF COMPANIES WITH THE POTENTIAL TO OPERATE A PYROLYSIS OIL BIO-REFINERY

### ENSYN AND RED ARROW

**Ensyn Corp**, is a small privately-owned company based in Ottawa, Ontario. It is the parent of several Ensyn companies, and was originated in 1989 as an outgrowth of research and development at the University of Western Ontario which dates back to the 1970's (www.ensyn.com). Ensyn developed its core technology, Rapid Thermal Processing (RTP™) to produce oil from biomass, especially wood and wood wastes. Ensyn also used related technology to upgrade heavy oil and bitumen. Ensyn Petroleum Inc., which was responsible for RTP applications in the petroleum sector, was recently sold to Ivanhoe Energy Inc. (www.ivanhoe-energy.com). Ivanhoe and Ensyn have overlapping directorships. Ensyn has built several R&D facilities and at least 7 plants that Ensyn considers commercial. The most recent and largest plant has an input design capacity of 160 tons of wood per day and is nearing completion in Renfrew, Ontario. Most of the plants owned by Ensyn, including the new Renfrew plant, have been built with assistance from the Canadian public sector. The Renfrew Plant, although commercial in size and capability, also includes R&D capabilities and has received government subsidies for over 50% of the capital cost. In addition, most of the Ensyn plants have relied primarily on relatively low-cost waste wood for raw material. These are important factors, which have contributed to the development of the pyrolysis oil industry in Canada. At its own plants Ensyn has made commercial quantities of natural resins, co-polymers, charcoal, and pyrolysis oil as well as other, chemical products. The most significant of these non-fuel products, in the context of this study, are the natural resins used as a partial substitute for phenolic resins in PF resin products. Ensyn is the only company in North America with the demonstrated capacity to design and build a bio-refinery based on pyrolysis oil that can produce commercial quantities of non-fuel products.

**Red Arrow Products Company** is a privately held company based in Manitowoc, Wisconsin (www.redarrowusa.com/products.htm) that is a leading manufacturer of food additives, especially smoke flavorings, for the commercial meat products industries. It is an integrated supplier of food additives and application equipment for food processors. Red Arrow developed technologies for extracting food flavorings from wood and entered into an agreement with Ensyn to supply it with an integrated bio-refinery based on selected wood raw materials. The bio-refinery produces food flavorings as well as pyrolysis oil that is used for heat and electric power for the plant. Red Arrow has two plants at Rhinelander, Wisconsin. The exclusive rights to use this technology in the food additives business are owned by Red Arrow. The two Red Arrow plants are the only examples that we know of a fully commercial bio-refinery that integrates the production of fuel and non-fuel products.

### DYNAMOTIVE ENERGY SYSTEMS CORPORATION

**DynaMotive Energy Systems Corporation**, based in Vancouver, British Columbia, is a public company traded on the OTCB. (www.dynamotive.com). It has affiliated companies in the US and UK. Its principal technology is a patented rapid pyrolysis process called Bio-Therm which was originally developed by RTI. It is primarily an R&D company, which has just entered the commercial development phase of pyrolysis oil production with the construction of its West Lorne Plant in Ontario. The West Lorne plant is a pyrolysis oil production facility designed to provide cogeneration power to a wood products company. It will use an Orenda gas turbine, which should be a more efficient way to produce electricity. The West Lorne Plant is substantially subsidized by two Canadian Government Agencies (the SDTC and TPC). DynaMotive has produced char and claims to be exploring the production of chemicals but it has no demonstrated capacity to operate a bio-refinery.

### RENEWABLE OIL INTERNATIONAL (ROI)

**Renewable Oil International (ROI**) based in Florence, Alabama is a very small private company that operates a small experimental plant in Alabama for the pyrolysis of poultry litter and other wastes (www.renewableoil.com). It is currently building a demonstration wood waste pyrolysis plant in Massachusetts with funding from the Massachusetts Technology Collaborative. ROI does not have the capability to operate a bio-refinery.

### OTHER COMPANIES

There are a few other companies that have related capabilities even though none of them have the current capability to build and operate a bio-refinery. **Enerkem**, headquartered in Montreal, is a small R&D and engineering services company that has expertise in pyrolysis and was founded by Dr. Esteban Chornet of the University of Sherbrooke in Quebec (www.enerkem.com). It is currently focused more on gasification technologies than pyrolysis. **Changing World Technologies (CWT)** is a small company that uses a proprietary process trade named Thermal Conversion Process (TCP) (www.changingworldtech.com). CWT converts agricultural and similar waste products to oil, char, and gas. It has constructed a waste processing plant in Carthage, Missouri. It does not have the demonstrated capability to process wood or construct and operate an integrated bio-refinery.

## REVIEW OF CHEMICALS DERIVED FROM PYROLYSIS OIL

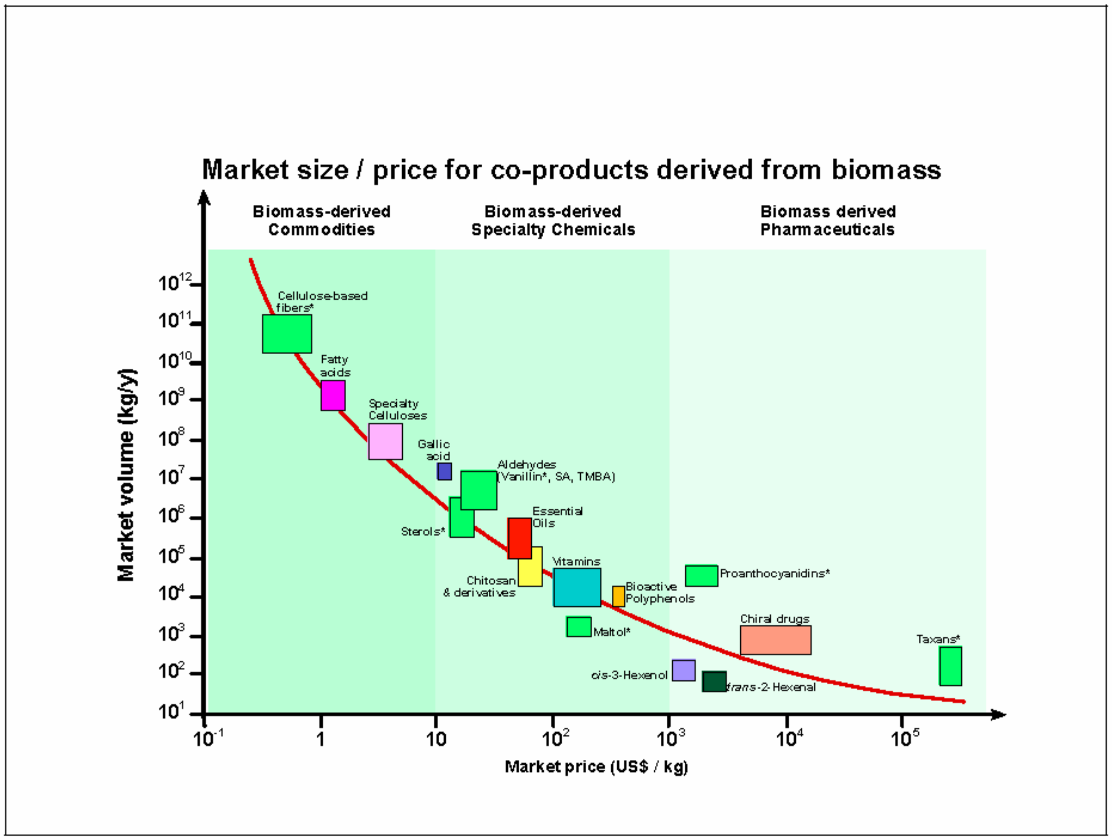
A review of the potential for chemical production was provided in the New Hampshire Bio-oil Opportunity Analysis. Figure 1 from that study[1] shows the range of co-products. This report does not duplicate that study but goes on to determine which, if any, of the chemical products have reached the stage of being commercial or nearly commercial products of a bio-refinery. This focus on commercial or near-commercial production is indicated by the overall objective of determining if a bio-refinery is feasible as part of an economic development strategy to increase and diversify the use of abundant low-grade wood in New Hampshire. A predominantly R&D facility would not meet that objective.

To be fully commercial, a product must have been produced in marketable quantities by methods which are commercially practical. The product must have been sold to end users or manufacturers who have successfully incorporated them into other products. In addition, the products must have been produced under market conditions that are self-supporting. This definition would exclude products that are produced by plants substantially subsidized on a project-specific basis. Near-commercial production is similar, except that the market conditions may not be self-supporting at present.

The process of evaluating chemical products began systematically, but it became apparent that there was very little publicly-available information on potential bio-refinery co-products. Apparently there are very few products that are even at an advanced R&D stage and far fewer are near-commercial. In addition, only Ensyn has the ability to develop an integrated bio-refinery. They are unable or unwilling to disclose their cost structure and other commercial information. As there are so few products in or near the commercial stage and the economics of these depend on the integration of the plant, a product- by- product evaluation was not possible. The market volume and market price scales on Figure 1 should be considered as illustrative of a trend. This is not backed by any market research results or verification that all the specific product categories can actually be produced commercially. Because of the lack of publicly available data on most of the potential co-products we considered, it was more practical to evaluate the applicability of existing or proposed models of bio-refineries.

[1] The figure was presented at the Maine Bio-Products Forum; Converting Cellulose into Sales, University of Maine at Orono March 2 2004 by Esteban Chornet, River Valley Pyrolysis Project. Dr. Chornet is with Enerkem in Montreal and Sherbrooke Quebec.

***Figure 1: Market size and price for co-products derived from biomass***




## COMMERCIAL BIO-REFINERY MODELS

There is only one existing example of a pyrolysis oil bio-refinery producing commercial chemical products in addition to fuels from wood. This is the Red Arrow Products Company, which produces food additives at two plants in Wisconsin. The Red Arrow model was therefore evaluated in the New Hampshire context. There is only one other model that is near commercial and that is a model advanced by Ensyn, based on the production of a phenolic resin substitute. This would be used to produce Phenol Formaldehyde resin for oriented strand board (OSB) manufacturing.

### MODEL BASED ON FOOD ADDITIVES (THE RED ARROW MODEL)

This model is exemplified by the two Red Arrow plants at Rhinelander, Wisconsin, where the company manufacturers a range of food flavorings and other additives, including a liquid smoke product. The technology to produce smoke flavorings from wood was developed independently by Red Arrow before the development of the integrated bio-refinery technology by Ensyn. The key factor is Red Arrow's technology and marketing capability combined with Ensyn's RTP technology for commercial scale pyrolysis oil production. In this facility, the food flavorings, which are high value products, are extracted from specific hardwood feedstocks by a pyrolysis process. The plant also produces pyrolysis oil and char that are used as fuel for the manufacturing plant. At present, Red Arrow together with Ensyn are the only companies in North America with the technology to produce these types of food additives in a commercial, integrated bio-refinery. The specific food products produced by Red Arrow are described on the company's web site (www.redarrowusa.com) but the specific chemical formulations and components are proprietary. Red Arrow owns the exclusive rights to this process for food additive production. Additional facilities using this model are dependent on Red Arrow. At present, it seems highly unlikely that Red Arrow would choose to expand its operations to New Hampshire.

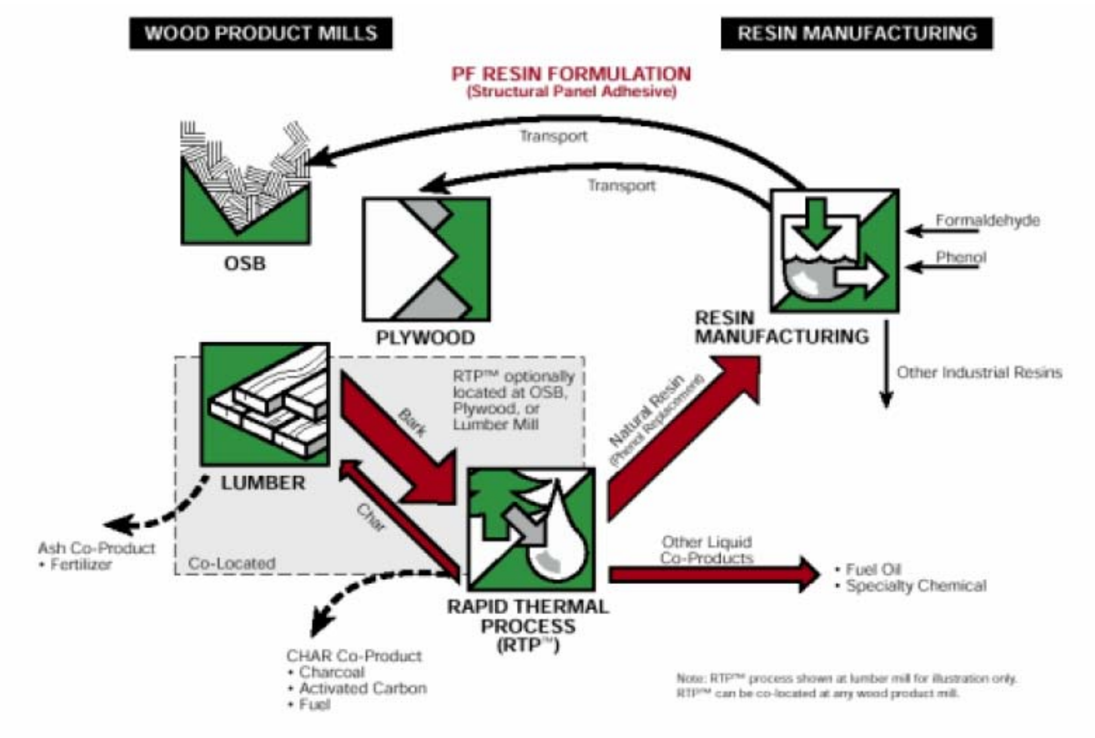
This model appears to work well at its present scale of approximately 100 green tons per day. At this scale, the consumption of wood would be small compared, for example, with a single 20 MW wood-fired power plant that would use 800 green tons per day. Therefore this model is unlikely to be the basis for a substantial economic development opportunity in the near future.

### MODEL BASED ON PHENOLIC RESIN MATERIALS (THE OSB MODEL)

Ensyn has advanced the concept of a wood products integrated bio-refinery that produces Natural Resins (NR) as a replacement for petroleum-based phenolic resins used in the production of Phenol Formaldehyde (PF) resins[1]. PF resins are the mostly widely used adhesives and binding agents in the manufacture of plywood, composite structural lumber and especially OSB. If the bio-refinery were co-located with a forest products factory it would be able to use the waste wood from the wood manufacturing as a feedstock. The bio-refinery in turn would produce relatively high value resins for the manufacture of plywood or OSB. This concept is illustrated in Figure 2.

[1] Ensyn, Use of Bark-Derived Phenol Substitute in Structural Panel Adhesives, Final Report Prepared by Ensyn Renewables Inc. for the US DOE December 2003.

***Figure 2: Bio-refinery concept based on natural resin production and waste wood from forest products proposed by Ensyn[1]***




The model illustrated in Figure 2 has not yet been implemented, but all the parts of the process have been demonstrated on a commercial scale, although the economic viability is as yet unproven. This model is most likely to be successful at an OSB plant. An OSB plant produces large quantities of waste wood and bark that can be used as the feedstock for pyrolysis oil production using the Ensyn RTP process. The pyrolysis oil plant produces the natural resin that can be used as a substitute for the phenolic resins in PF resins which is a key component in the manufacture of OSB. Surplus pyrolysis oil can then also be used to produce heat and electric power for the OSB plant. OSB is especially attractive because it uses more resin than plywood and it is a rapidly growing market. Total North American OSB production now exceeds structural plywood production.

Demonstration of the commercial capability to produce OSB using natural resin substitutes for petroleum-based phenolic resins was achieved in a major demonstration project between 2001 and 2003. The team was led by Ensyn and cost $2.4 million of which 60% was funded by the US DOE.[2] The project involved Louisiana Pacific and Weyerhaeuser that together make 50% of the North American OSB and Tembec, a major Canadian OSB and OSB resin maker. Dynea and Georgia

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[1] Ensyn, op cit.

[2] Ensyn, op cit.

Pacific, two other leading resin makers, were also involved. Ensyn made commercial quantities of the NR product that substitutes for phenolic resins in PF resin formulations. NR product can be substituted for up to 50% of the phenolic resins, although the tested commercial OSB panels were based on 40% substitution. Using 40% NR for phenolic resins, the cooperating companies made 50,000 OSB panels that met the APA industry standards for OSB. Independent tests indicated that there was no significant difference between NR OSB and conventional OSB with respect to odors, which had previously been noted as a potential problem. The product has received the EcoLogo label from Environment Canada's green labeling program.[1] The renewable characteristics of NR-based products create the possibility of a premium price for the product in green markets.

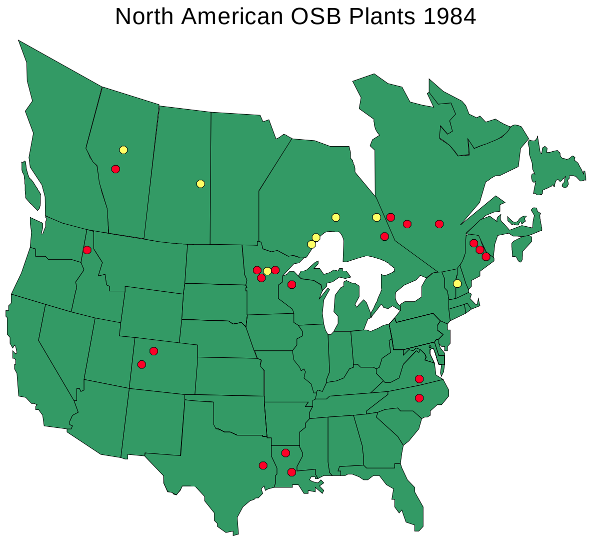
This model is not yet commercial but Ensyn has stated that it is actively pursuing commercial development. The team that produced the demonstration products includes the major players in this industry and therefore we might expect that one or more of them would be interested in production. This model is apparently attractive although there is no publicly-available cost or price information for the NR product.

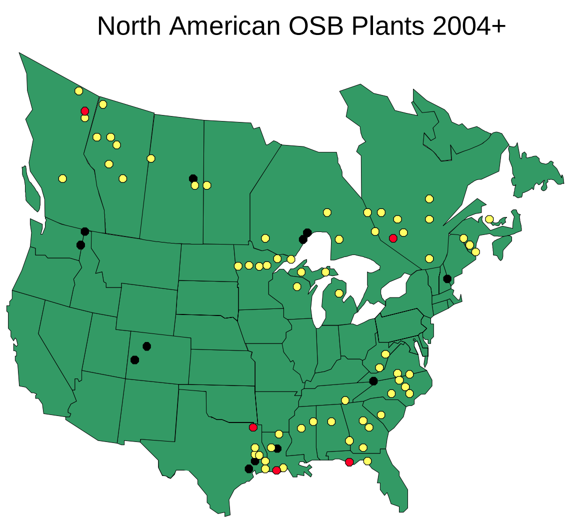
It is unlikely that this model can be applied in New Hampshire. Figure 3 shows the location of OSB plants. It can be seen that there are few plants in the Northeast and these are distant from New Hampshire. Because of the species availability, wood price, and proximity to the most rapidly growing markets, New England is considered to be an unlikely location for a new OSB plant. A recent study of OSB production in Maine tends to confirm this conclusion[2]. Most of the growth in recent years has been in the South, northern Midwestern Lakes States, and parts of Canada. The US South and parts of Canada are now the most probable locations for new OSB plants.

[1] Environment Canada Environmental Choice Program, www.environmentalchoice.com

[2] Innovative Natural Resource Solutions LLC, Current Conditions and Factors Influencing the Future of Maine's Forest Products Industry, In "Maine's Future Economy Project", Maine Department of Conservation March 2005.

***Figure 3: Location of OSB plants in North America 1984 and 2004[1]***




*Note: Yellow =existing plants, Red = new plants, black = closed plant*

[1] Innovative Natural Resource Solutions LLC, op cit.

## COMMERCIAL STAND-ALONE PYROLYSIS OIL PRODUCTION

Two of the pyrolysis oil manufacturers indicated to us that stand-alone production of pyrolysis oil and sale to unaffiliated customers was a possible market. This was despite the fact that none of the three pyrolysis oil producers had succeeded in selling any significant quantity of oil to unaffiliated buyers. Except for demonstration purposes, all the pyrolysis oil has been sold as part of integrated or linked operations. Also, as far as we can determine, all the pyrolysis oil production, except at the Red Arrow plants, has been supported with government funds.

Although the principal focus of this study is the market for non-fuel products, a preliminary review of the possible markets for pyrolysis oil alone was undertaken. This model considers the market prospects for pyrolysis oil sales to an existing or new commercial or industrial user of #6 fuel oil, or distillate fuel oil that has no business partnership with the pyrolysis oil producer.

The market characteristics of pyrolysis oil compared to #6 or # 2 fuel oil and biodiesel were reviewed from the perspective of an unaffiliated customer. This was based principally upon the experience of Resource Systems Group as a consultant to a very wide range of public and private sector clients that burn #2 and #6 oil in commercial and industrial boilers. Some of these fuel oil users are evaluating biomass fuels including wood and biodiesel. The comparison of the characteristics of these fuels is given in Table 1. Pyrolysis oil compared to fuel oil has many disadvantages, notably lower heat content, which increases transportation cost and fuel storage costs. It is acidic which makes it corrosive and requires corrosion- resistant storage and handling at higher cost. These characteristics combined mean that pyrolysis oil would need additional equipment and space because it cannot share storage with fuel oil. Pyrolysis oil cannot be mixed with fuel oil so co-firing is difficult. In addition, the burners of fuel oil boilers need to be modified to burn pyrolysis oil. Air permit modifications will also be required. In addition to these technical obstacles, the pyrolysis oil customer would be dependent on a single supplier with all the risks of continuity of supply, financial stability and price increases.

To those fuel oil users who want to use a renewable fuel with minimal direct greenhouse gas emissions, biodiesel is now available from multiple suppliers throughout New England including New Hampshire. Unlike pyrolysis oil, it has very few disadvantages and several advantages. Because biodiesel can be co-fired and mixed with fuel oil, it can share storage and handling equipment with fuel oil and requires very little, if any, modification to the boiler plant. Biodiesel blends are currently subsidized by a federal tax credit, although prices are still higher than fuel oil. The market for the fuel is expected to grow. Biodiesel is also a practical fuel for residential and small commercial users and can be used in diesel engines.

The conclusion of the review was that it is highly unlikely that any unaffiliated customer would elect to use pyrolysis oil. This conclusion is based on the additional fuel handling and boiler modification costs, regulatory uncertainty, technical support availability and price risks. The disadvantage that pyrolysis oil has, when compared to conventional fuels or biodiesel, could only be overcome by the producer or the public sector carrying the additional cost and risk.

***Table 1: Comparison of Pyrolysis Oil Characteristics with Fuel Oil and Biodiesel9***

| Fuel Characteristics | Fuel Oil #2 (#6)[10] | Biodiesel | Pyrolysis oil |
|---|---|---|---|
| Heating value (Btu/ US Gal) | 138,500 (153,200) | 118,296 | 75,500 to 81,500 |
| Water content (%) | Negligible | Negligible | 15% to 40% |
| Density (kg/L) | 0.85 (0.95) | 0.88 | 1.2 |
| Ash Content (%) | 0.05 to 0.1 % | 0.07% | 0.02 % to 0.16 % |
| Acidity (pH) | near neutral | 8.5 | 2.5 |
| Sulfur content ppm | 500 to 50,000 | 15 to 500 | < 300 |
| Net Direct CO2 emissions (lb/MMBtu) [11] | 161 (174) | Near zero | Near zero |
| Product standards | ASTM standards | ASTM standard | None |
| Storage requirements | Standard steel tanks | Standard steel tanks | Corrosion resistant tanks |
| Handling | Standard pumps and trucks | Standard pumps and trucks | Corrosion resistant pumps and trucks |
| Miscible with petroleum liquids | Yes | Yes | No |
| Suppliers / Availability | Multiple suppliers and national availability | Multiple suppliers and availability in NH | No open market suppliers |
| Existing government support program in US. | Multiple support programs | US and some state tax incentives | Uncertain |

Sources: Ensyn, National Biodiesel Board, US EPA Compilation of Air Pollution Emission Factors AP42, US DOE NREL, Power Technology Data Book 2003

[10] Data specific to # 6 fuel oil are shown in parentheses.

[11] Net Direct CO2 emissions are the combustion emissions minus CO2 fixed in plant growth for wood based pyrolysis oil and biodiesel. No allowance is made for CO2 emissions from fossil fuel combustion in extraction, harvesting, processing or transportation for any fuel.

At present pyrolysis oil is not a demonstrated commercial fuel. It could be used in a pilot or demonstration facility by a steam or steam electric generator in partnership with one of the three pyrolysis oil manufacturers. This would require a subsidy. Based on the experience with several plants in Canada built by Ensyn and Dynamotive and one under development in Massachusetts by Renewable Oil International, this would require a subsidy of between 50% and 80% of the capital cost, assuming that the wood supply is relatively low-cost waste. If the wood were to be harvested, then additional subsidies would probably be needed. If electric power were generated and sold into the Massachusetts or Connecticut Renewable Portfolio Standard (RPS) markets, then the level of subsidy might be reduced. However, there are unresolved inter-state policy implications in how a subsidized electric generator in one state might be treated by another. The market premium for RPS-qualifying generation will also be affected by the outcome of the permitting process for several major wind projects and the proposed development of additional wood fired power plants.

## WOOD AVAILABILITY AND PRICING FOR A BIO-REFINERY

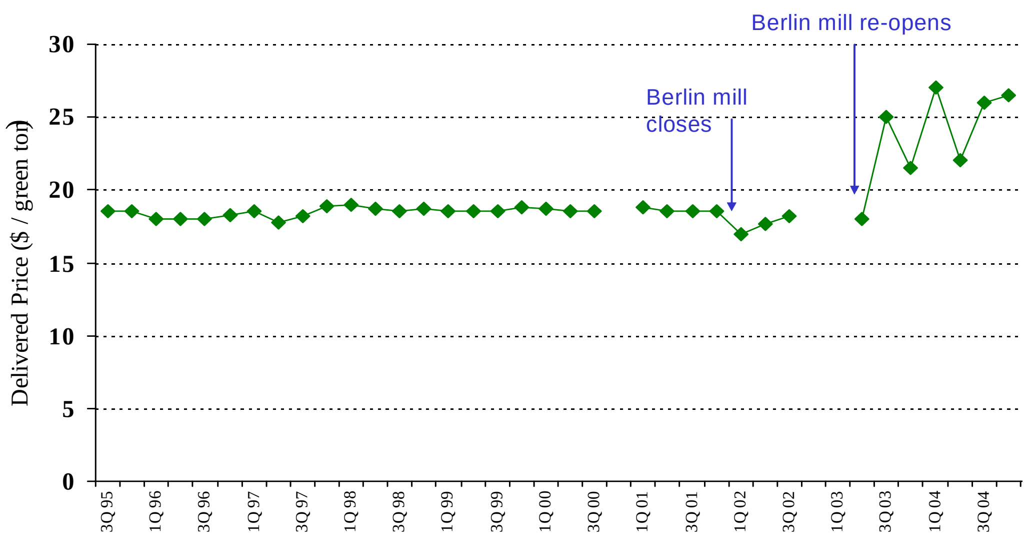
The availability and pricing of wood chips is a key variable in the economics of any facility producing pyrolysis oil. For purposes of this analysis, it is assumed that whole-tree chips, made from a variety of species with bark on, are the feedstock for production of pyrolysis oil. Any requirements that are more stringent than this (for example specific species or bark-free) would increase the price of wood.

For a long period of time, the price of whole tree chips used at regional biomass plants was relatively constant, with prices in Northern New Hampshire around $18.00 - $19.00 per green ton, delivered. This is no longer a good number for delivered wood, and any project using whole-tree chips should conduct sensitivity analysis using a range of wood fuel costs.

Since 2002, the price of chips has increased, with wood prices in Northern New Hampshire rising to the high $20s per green ton. One of the causes of this increase may be the loss of regional supply infrastructure that occurred during the time period when the pulp and paper mill in nearby Berlin – Gorham, NH was closed. Though the facility emerged from bankruptcy with a new owner, and is an active and productive mill today, financial hardship caused by the closure of the facility for six quarters (as well as unpaid debts incurred by the previous owner) is often cited as a reason that some loggers left the business, or others reduced their logging capacity. However, it is important to note that wood prices around Northern New England have increased during this time period, so the local situation in Berlin-Gorham, NH is, at most, one of a number of contributing factors in the increase in wood prices.

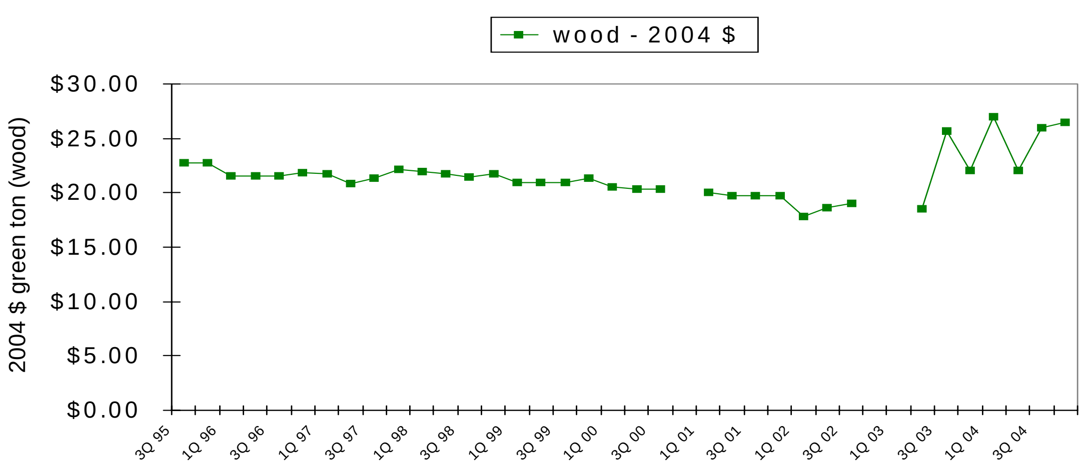
Figure 4 shows the historic price of fuel chips in Northern New Hampshire, with the closure and re-opening of the Berlin-Gorham paper mill noted. It should be noted that, adjusted for inflation, the price of delivered wood was falling from 1995 until 2003. In 2004 dollars, whole tree chips prices were almost $23.00 per green ton in 1995, and slowly declined in inflation-adjusted price through 2003. Figure 5 shows the price of chips in northern New Hampshire, with all information converted to 2004 dollars.

*Figure 4: Delivered Price of Whole-Tree Chips, Northern NH, 1995 - 2004*




Data Source: *NHTOA Timber Crier*

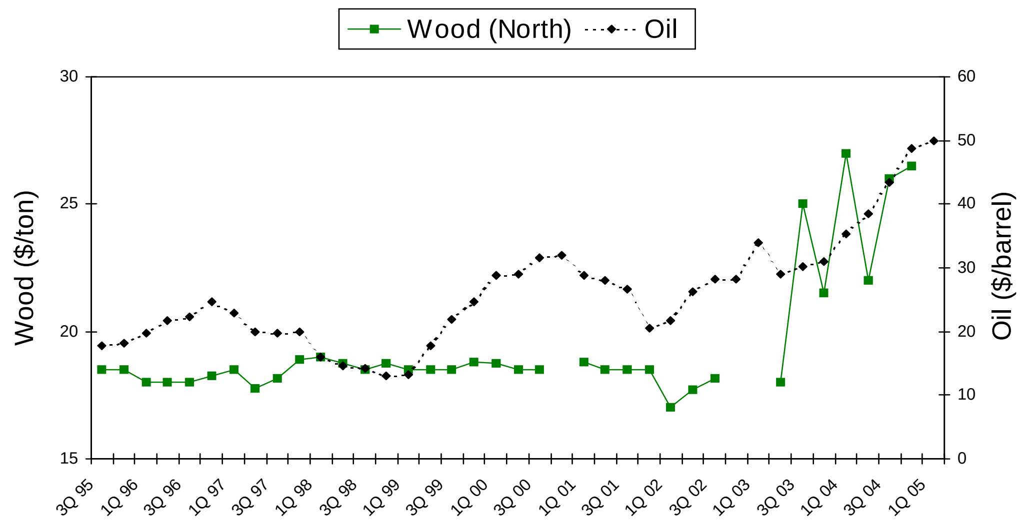
*Figure 5: Inflation-Adjusted Delivered Price of Whole-Tree Chips, Northern NH, 1995 - 2004*




Data Source: *Figure 4 adjusted for inflation using the US Bureau of Labor Statistics consumer price index.*

The increase in whole-tree chip prices has coincided with a dramatic increase in the price of oil, rising to over $60 per barrel in the summer of 2005. Petroleum, in the form of diesel fuel to harvest, skid, chip and transport whole-tree chips, is a critical input to the cost of wood fuel. Figure 6 shows the price of both wood fuel (green tons, delivered in Northern New Hampshire) and oil (U.S. light, sweet crude).

***Figure 6: Wood and Oil Prices, 1995 - 2004***



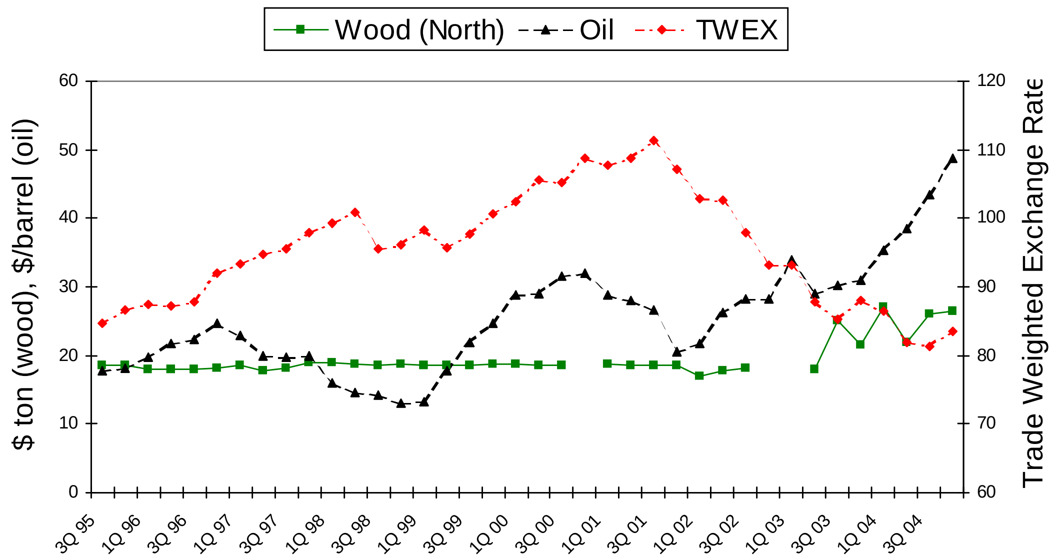

Data Sources: *NHTOA Timber Crier, US DOE Energy Information Agency*

While there appears to be a relationship between oil prices and wood fuel prices, the relationship does not explain the entire recent rise in wood fuel prices. When conducting a regression analysis, the $R^2$ value, or co-efficient of determination, between wood chip prices and oil prices is 0.4447; in other words, 44% of the variation in wood chip prices can be explained by changes in oil prices.

Another factor in the recent increase in wood chip prices may be competition from other users, primarily the region's pulp and paper industry. In addition to the previously mentioned mill in Berlin-Gorham, NH, a number of Maine and New York facilities purchase pulpwood and chips (including fuel chips) from the same wood basket a Northern NH pyrolysis facility would use. The paper industry competes to sell its product globally, and is highly impacted by the relative strength of the U.S. dollar against foreign currencies. When the U.S. dollar is "strong", U.S. manufacturers face increased difficulties when selling products that compete against foreign goods, thus causing reduction in production or providing added incentive to control wood and other costs. When the U.S. dollar is "weak", it makes it easier for U.S. manufacturers to sell their products here and abroad, and provides some flexibility in increasing wood prices to meet increased product demand.

Figure 7 shows the price of wood, oil and the "trade weighted exchange rate" (TWEX), a weighted average of the foreign exchange value of the U.S. dollar against a subset of the broad index currencies that circulate widely outside the country of issue. The TWEX is used here as a measure of the strength of the dollar, and its impacts on the price of fuel chips is examined.

***Figure 7: Price of Whole-Tree Chips, Oil and the Trade-Weighted Exchange Rate12***




When a regression is performed on the price of wood chips and the TWEX, the $R^2$ value is a relatively low 0.269, meaning that 27% of the variation in wood prices can be explained by changes in the strength of U.S. currency.

However, when oil prices and the TWEX are viewed together, the regression analysis provides an $R^2$ value of 0.5786. This indicates that 58% of the variation in wood prices can be explained by these two variables. Obviously, a number of other factors influence the cost of wood. In Northern New Hampshire, these include:

1) Reluctance by suppliers to invest in new equipment due to uncertainty over the future reliability of existing markets, particularly biomass markets, following the expiration of rate-orders that guarantee the purchase of electric output at prices that allow a facility to make a profit. For example, the rate-order for Pinetree-Bethlehem expires in November 2006; the future of this market is uncertain.

[12] Data Sources: NHTOA *Timber Crier* (wood), U.S. DOE Energy Information Agency (oil), and Federal Reserve Bank of St. Louis (TWEX)

2) Uncertainty over whether New Hampshire will adopt public policy that supports existing biomass facilities, or whether proposed changes in other states Renewable Portfolio Standards (RPS) will favor existing New Hampshire facilities. For example, Massachusetts has proposed changes to its RPS that would make it easier and less costly for existing New Hampshire facilities to qualify for participation in that state's program.

3) Questions over how much total demand will exist for biomass chips, including discussion regarding the impact of PSNH's 50 MW Northern Wood Power Project at Schiller Station (scheduled to begin operation in the third quarter of 2006) on regional wood prices. Access Energy has proposed a 20 MW facility in Ludlow, Vermont. Assuming permitting, financing and construction progress, this facility is expected to begin operation in early 2008.

4) A change in the demographics of the logging workforce, where a number of anecdotal reports have people either leaving logging or discouraging their sons from entering the profession. Because logging has historically been a profession passed down from father to son, with children learning through de-facto apprenticeships, this reported change in demographics of the logging workforce is a long-term concern for the wood supply.

5) Specific and localized weather events, such as the long mud season experienced in Northern New England in spring 2005, can have a meaningful short-term impact on the price of biomass fuel.

## CONCLUSIONS

1) The primary overall conclusion of the study is that the prospects are poor for developing a commercial bio-refinery based on pyrolysis oil from wood in New Hampshire. Only Ensyn has the demonstrated capability to make products other than oil, gas and char and Red Arrow owns the technology to produce food additives by this process. Food additive manufacture by Red Arrow is clearly economically feasible but the cost and pricing structures are proprietary. However, it is unlikely that Red Arrow would expand operations in New Hampshire. Even if a Red Arrow plant were built, the typical wood consumption levels of about 100 tons per day are not the basis for a significant economic development on its own. Natural resins to make PF resins for OSB have been produced in commercial quantities by Ensyn for demonstration purposes but full-scale commercial application would require a partnership with an OSB manufacturer. This would most likely occur in the Southern US or in Canada.

2) A secondary conclusion is that open market sales of pyrolysis oil are not practical at the present time in New Hampshire, even if the price on a heat content basis were at or below conventional oil. This is because of the additional costs and risks associated. At present pyrolysis oil is not a proven commercial fuel. It could be used in a pilot or demonstration facility by a steam or steam-electric

generator in partnership with one of the three pyrolysis oil manufacturers. Based on the experience with several plants in Canada and one under development in Massachusetts, this would require a subsidy of between 50% and 80% of the capital cost, assuming that the wood supply is relatively low-cost waste. If the wood were to be harvested at current market prices, then other subsidies would probably be needed. If electric power were generated and sold into the Massachusetts or Connecticut RPS markets, then the level of subsidy might be reduced. However, there are unresolved inter-state policy implications in how a subsidized electric generator in one state might be treated by another.

3) The conclusions of this study apply only to pyrolysis oil based bio-refining in New Hampshire. Other wood based technologies such as gasification, enzymatic conversion to ethanol and direct industrial-scale combustion have different attributes, production economics and markets.